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PRACTICE OF MICROSEISMIC MONITORING FOR MINING ACTIVITIES

T.I. Vladut
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April 1985

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PRACTICE OF MICROSEISMIC MONITORING FOR MINING ACTIVITIES

by

T.I. Vladut*

ABSTRACT

The paper reviews the application of microseismic monitoring to different mining activities with a view to evaluating its future applications need for the development of more specialized equipment and a better understanding of the process. Some of the basic physical elements of microseismic monitoring related to the available equipment are discussed. Analysis of field tests from underground mining is made for conclusions related to both hard and soft rock mining and on rock bursting. To illustrate microseismic monitoring, data from a study of stability of a pit slope in an open pit were used. Although the main emphasis of the discussion is on field testing, the contribution of laboratory measurements must also be considered.

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UTILISATION DE LA SURVEILLANCE MOCROSISMIQUE DANS LES TRAVAUX MINIERS

par

T.I. Vladut*

RÉSUMÉ

Le document présente un examen rétrospectif de l'utilisation de la surveillance microsismique dans divers travaux miniers dans le but d'évaluer les besoins futurs afin de mettre au point de l'équipement plus spécialisé et d'acquérir une meilleure compréhension de la technique. L'étude porte sur certain des éléments physiques de base de la surveillance microsismique inhérents à l'équipement disponible. On fait l'analyse d'essais sur le terrain dans les mines souterraines pour tenter de résoudre les difficultés relatives à l'exploitation minière de la roche tendre et de la roche dure et au repérage de la source des coups de toit. On utilise des données obtenues à partir d'une étude de la stabilité des pentes dans une carrière à ciel ouvert pour illustrer la technique de surveillance microsismique. Bien que l'étude porte surtout sur les essais sur le terrain, l'importance des mesures en laboratoire doit également être soulignée.

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INTRODUCTION

Following the pioneering study by Obert (1) on the relationship between microseismic emission and rock stress, the mining industry has been using this technology for improving safety. Developments in microseismic monitoring during the last decade are best documented in the international conferences organized by Professor H. Reginald Hardy, Jr. (2) at the Pennsylvania State University. Better understanding and the significant extension of its application to other fields such as petroleum, underground waste disposal, civil engineering and avalanche monitoring justify its further development.

Applications of microseismic monitoring in mining is growing in different fields, although ground control for improved safety appears to be the principal area of interest. The efficiency of mechanized mining is highly influenced by geotechnical disturbances and their detection in advance by microseismic monitoring is the reason so many Canadian mines are using this technique. The extensive participation by the mineral industry in the symposium on microseismic monitoring, held in Sudbury in August 1984 is a measure of this interest. Different types of microseismic measurements in about seventeen mines were discussed in this symposium. This trend is in keeping with similar development around the world (Table 1) where the main objective in most of these application is to reduce the hazard of rock bursts.

Microseismic signals are also monitored for other types of rock failure. This paper discusses the application of microseismic monitoring in evaluating slope stabilities in a surface coal mining operation.

Application of microseismic techniques as an early warning systems requires an understanding of some of the associated phenomena as well as that of the instrumentation.

GEOMECHANICAL INTERPRETATION OF MICROSEISMIC EMISSIONS

Mining activity alters the stress equilibrium in the surrounding rocks which may result in failure. The process of failure of ground is

Table 1 - Microseismic monitoring of rockbursts

Location	Mineral	Activity*	Instrumentation	Observation
Star Mine, Hecla, USA	lead-zinc, silver	. 6	24 channel	30% successful prediction
East Malartic,Can	gold		16 channel	observations before mine closure
Western Mine S.Af.	gold	1.5-2.5	4 tridimensional monitors,	3000m depth
Shortland, Aust.	coal		4 detectors	accelerometers
Mid Continental, USA	coal		multi channels	frequency response, 10-110 Khz
Cynheidre Coll, UK	coal		single channel	accelerometers & geophones
Akabira Mine, Japan	coal		2 channel	for advance boring
Minami-Obyubari, Japan	coal		2 channel	for advance boring
Blyvoorritzicht, S.Af.	gold		30 geophones	depth up to 3800m
Uppsala, Sweden	iron	max 3.2	-	3 dimensional
Mount isa-Aust.	copper, lead-zinc		32 channels	array, cut and fill stopping
Szombierki, Poland	coal		4 & 7 channels	longwall and hydraulic backfill
Ruhr, W.Germany	coal		12 geophones	measurements related to destressing
Westcliff Coll. Aust.	coal		single channel	depth 200m
Henderson Mine, Col. USA	Molybden		7 geophones	block caving method
Kleofas, Poland	coal		stationary multi ch. or portable single ch.	-
Flaconbridge, Ont.	nickel-copper	3.2-3.5	32 ch., 25 OMP monitor	900-1800m depth, cut & fill
Wawa, Ont.	sidenite, iron ore		1 ch., McPhar	inconclusive test
Campbell Mine, Ont.	gold		32 ch., Electrolab	pillar stability
Geco Mine, N.B.	-		1 ch., McPhar	-
Chadbourne, Quebec	-		1 ch., McPhar	inconclusive test
Brunswick No. 12, N.B.	zinc-lead, copper		1 ch., McPhar	cut and fill
Gaspe Mine	copper		1 ch., McPhar	information on scaling
Creighton Mine, Ont.	nickel	4.0	16 ch., Electrolab	shear slippage shaft No. 5 3200-3800 level
Potash Corp. Sask.	potash	2-1	1 ch McPhar	mine induced seismicity

*maximum magnitude on Richter Scale

is always associated with a release of energy. Microseismic monitoring is based on the principle that rock failure is preceded by gradual energy emissions on a micro-scale and early detection of the pattern of the emission can be used in locating any critical stress build up. The emission of energy from failing rock may be seismic or microseismic as differentiated by the size of energy emission. Large energy emissions are measured on the Richter Scale of seismic activities. Microseismic activities are the emissions of low energy level and are measured in terms of the frequency and occurrence (number count) of the released energy. The physical significance of both the emissions is the same and is related to the intensity of the fracture development.

For utilization of microseismic measurements as an early warning of rock failure the interpretation of the physical meaning of such energy release could be quite useful. An easy interpretation could be made using the Richter approach for the defining energy release associated with seismic activity. The fractures associated with seismic phenomena, without going into the details of rock properties, may be expressed as:

$$OF = 10^{m-3} \text{ (in mm)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

in which OF is the induced offset of a failure fracture of 1 km of length and m is the strength of an seismic event expressed as a magnitude on the Richter Scale. This relationship implies that an offset of 1 cm corresponds to a Magnitude 4 event, 1 mm for an event of Magnitude, 3 and 0.01 mm for an events of Magnitude 1.

Such qualitative interpretation of the intensity of fracture development from seismological data may not be fully applicable to the lower range of energy emissions. In this case it is essential that the nature of the material be taken into consideration. Although the actual interpretation of fracture intensity is related to seismological data, its use is only appropriate as a reference to evaluate the order of magnitude of the induced fracturation.

THE STATUS OF MICROSEISMIC METHODS RELATIVE TO IN GEOPHYSICAL MEASUREMENTS

Geophysical measurements are made to detect natural or induced fields e.g. electrical, radioactive, magnetic. They identify change in state of the body observed. In propecting geophysics most commonly used to locate the orebody. A basic understanding of the local geology is essential to make use of geophysical measurements. One of the common methods of reducing the uncertainty of geophysical information is to use several types of geophysical measurements (Fig. 1). As an example use is made of seismic and electrical data for a rough estimate of the excavability of ground (Fig. 2)

In prospecting applications the geological body observed is in a steady state conditions. Measurements on bodies being mined will vary as mining advances differ from. Mining and other ctivities, such as oil production are examples of situations where changes in the state of the body progresses with depletion. It is stressed that initial measurements may refer to the natural microseismic emission which is encountered almost everywhere. As in any geophysical observation, successful use of the measurements depends on the particular method and on the capability to differentiate from the natural emission. Application of geophysical methods to mining problems is facilitated by the fact that the orebody is known and access to the disturbance of interest is much better.

Application of microseismic monitoring in mining environments has good potential for detecting emissions of significant strength in a known geological environment. Stress change due to mining could be evaluated in advance of mining and so enhance the physical interpretation of stress related microseismic emissions.

SPECIFICS OF MICROSEISMIC MONITORING

Discovery of microseismic emission in rocks under stress was accidental and its significance was not fully realized at first. It was discovered while investigating the possible dependence of seismic velocity on the pillar load in a lead-zinc mine in Oklahoma.

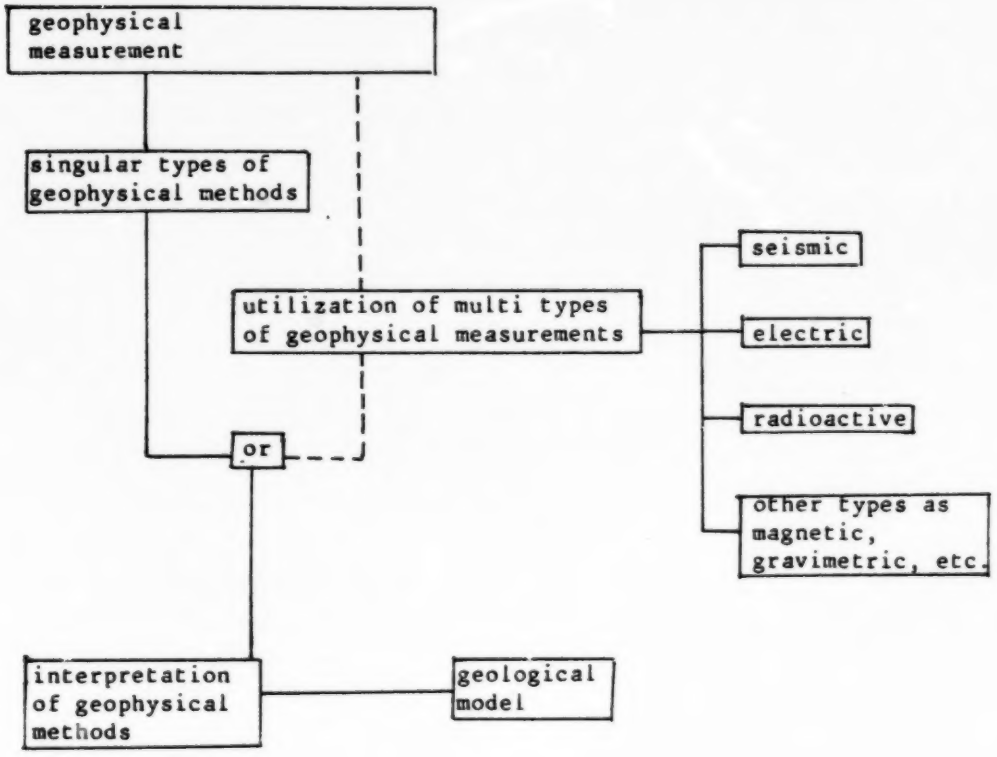

Fig. 1 - Geophysical measurements utilized for prospections

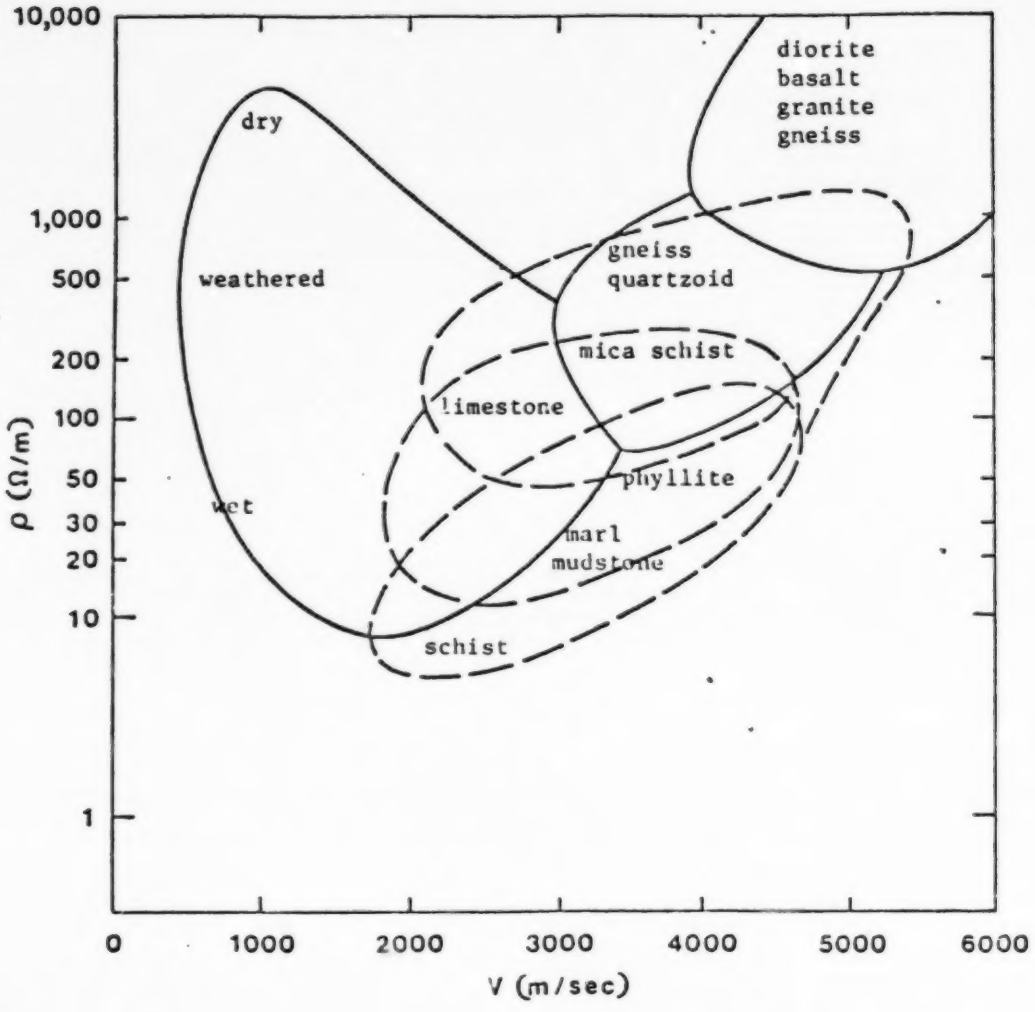

Fig. 2 - Evaluation of rock excavability, suggested by geophysical methods. Geophysical data: resistivity - vertical scale - and seismic velocity - horizontal scale (15).

The significance of the method rests on the fact that microseismic emissions are generated more frequently at high stress, a condition which precedes failure or major energy release. Therefore, the detection of the source of such emissions may serve as an early warning. It is emphasized that this does not require a knowledge of the mechanical properties of the surrounding rocks. Any rock under stress tends to reach equilibrium through small scale internal adjustments. Close to the failure stage these adjustments become more frequent and are characterized by the release of energy of seismic or audible nature.

One of the simplest methods in evalating stress changes and rock response is based on detecting and computing the number of emissions associated with the stress adjustments (Fig. 3). Several other physical parameters of microseismic emissions such as frequency, velocity, intensity, amplitude of wave length, may be measured or calculated. The most common parameters for such measurement and data processing are summarized in Table 2.

Table 2 - Summary of measurements to monitor microseismic activities

Type of measurements	Data referred
1. Number of events	- rate of emission - accumulated activity
2. Microseismic amplitude	- maximum amplitude of event
3. Microseismic energy	- magnitude - total released energy - energy release rate - energy per event

There has been a significant development in the instrumentation and technique of microseismic monitoring recently. This specially relates to detecting signals from low energy release which otherwise might be lost or obscured by other noises around the mining workings. Techniques of amplification and preamplification through transducers and wire or wireless transmission have substantially improved detection limits. Details on

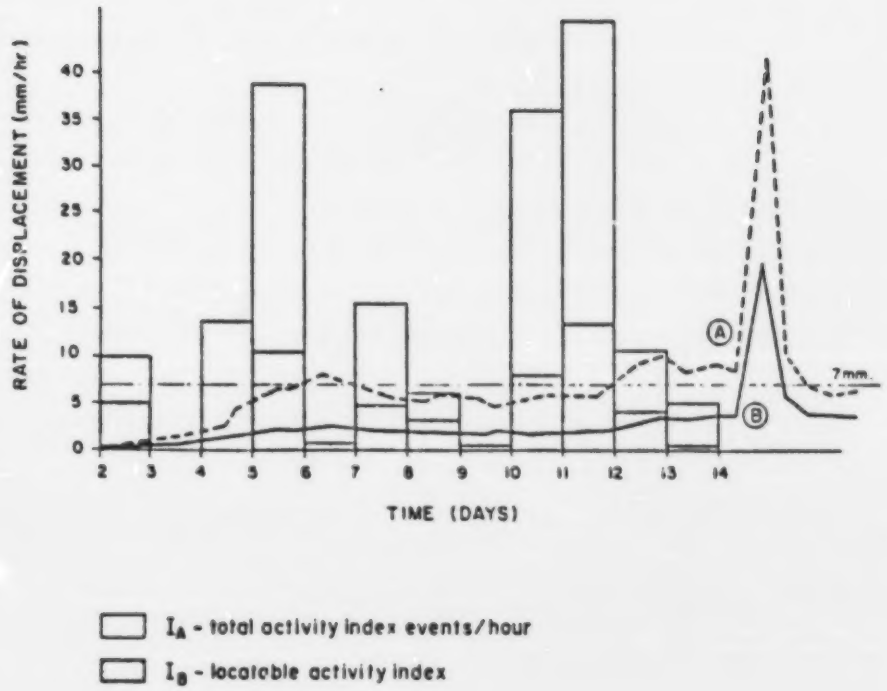

Fig. 3 - Relationship cf microseismic activity and displacement measured by EDM (electronic distance measurements). Data originated from pit slope monitoring Cardinal River Coal Mine 1984, a CANMET, USBM joing project (17).

transducer selection, accelerometers or velocity gauge etc are given elsewhere (3). The hardware for any microseismic measurement is quite complex and its selection must be made by qualified personnel. However, any choice for the selection of the available equipment should be made by a team of professionals in which the mining engineer must decide on the suitability of any equipment for the specific site and the scope of work. Of course, previous applications in similar mining situation may be helpful in this respect.

MICROSEISMICITY AS AN ASSOCIATED PHENOMENON IN ENGINEERING PROJECTS

Most of the microseismic energy released in fracturation is elastic energy as in an overstressed spring. The frequency range of this emission is of significance. Figure 4 indicates the different frequencies in relation to application areas.

The effect of mining on rock mass movement is well known in both underground and surface mining. Miners know that underground rock "talks" and "bumps" in response to stress changes induced by mining. It has been established that seismic events induced by mining activity radiate energy of a magnitude ranging from microseismic motions to large bump and rockbursts corresponding to a seismic magnitude of five on the Richter Scale.

Seismic activity in mining has been studied in various mines, for example, gold mines by Iernaudez (4), coal mines by Westbrook (5) and potash mines by Gendzwill (6). No definite conclusions on the effect of rock properties (whether brittle or ductile) could be drawn. Rock failure in the regions of maximum stress concentration near the edges of these excavations depend on the nature of the mining activity. The location of seismic events is found to occur within tens of meters of the advancing faces.

Microseismic detection technology has no doubt contributed to safety and ground control (7,8). It is, however, quite difficult to separate natural earthquakes from man-induced events near active mining areas. The problem is that many mines are often located in seismic regions and blasting is always associated with mining.

Even with these limitations, some well-documented cases have been recorded. Direct relationships between tremors noticed in Johannesburg

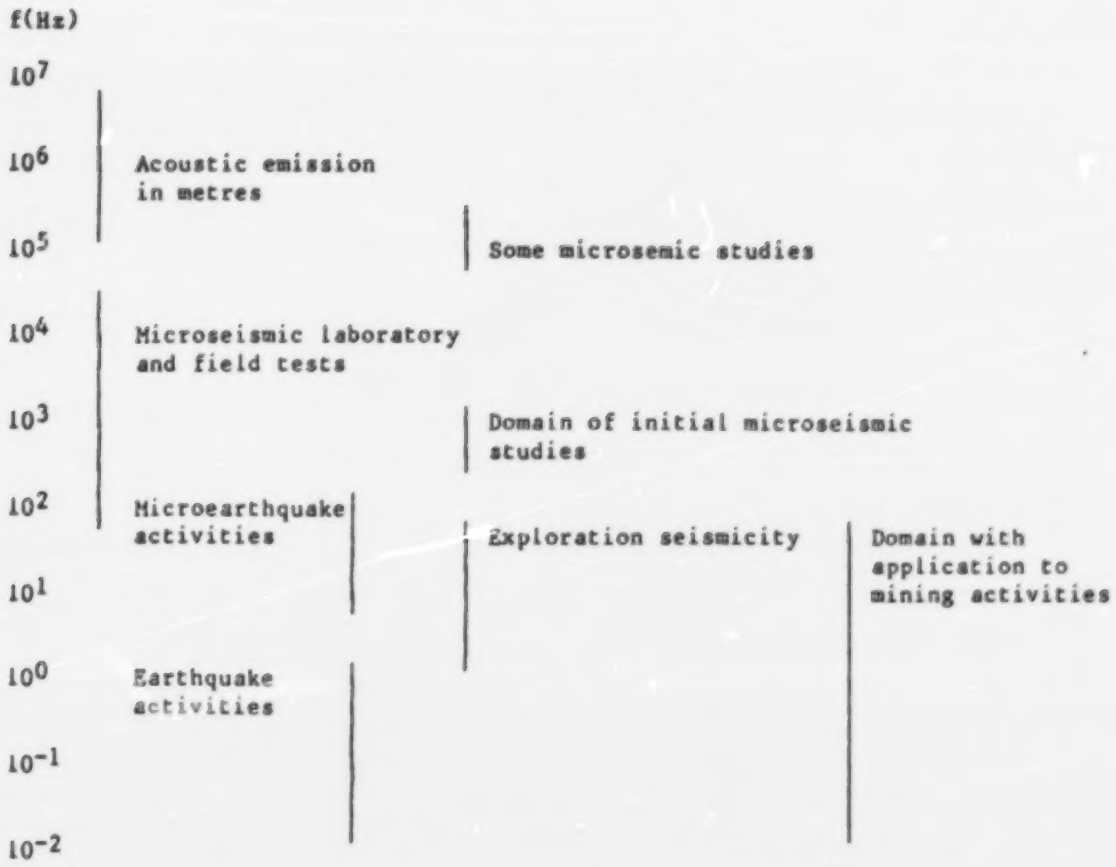

Fig. 4 - Microseismic and seismic frequency ranges (f), area of applications

South Africa and gold mining was established and the location of the tremors were closely identified with the location of active mining (9). Tremors with magnitude between 2 and 4.1 were recorded originating in gold mines of the Witwaterstand (10). The gold bearing strata of a thickness of about one meter was extracted almost completely over an area of many square kilometers.

Earth tremors have affected North Staffordshire (U.K.) since the last century where coal extraction has been extensive. Several intensive tremors estimated to be of magnitude 3.4 affected an area of about 4 square kilometers. Here a clear relationship between the earth tremors and mining was established. The series of earth tremors was caused by mining of seams at a depth of nearly one kilometer.

Seismic events related to mining activities in Canada were reviewed by W.G. Milne and M.J. Berry at the First International Symposium on Induced Seismicity held in Banff in 1975 (11). Other examples, such as events with a magnitude of 3.9 on the Richter Scale, at Malartic Mine in Quebec in 1975 are also known. An occurrence of four earthquakes near Saskatoon (1979-1980), in an historically non seismic region, is connected with potash mining operations. These tremors were of a magnitude between 2.3 and 3.0 on the Richter Scale and were interpreted to be the result of mining where competent rocks above the mine undergo spasmodical movements. References on more recent seismic activities (in 1984) are included in Table 1 and publications such as Davidge 1984 etc. (12) and others were presented at the recent symposium (13). Mining practices have changed and this may indirectly change the frequency of seismic activities. The triggering conditions and the seismicity itself is controlled by stress concentrations. Improvement of ground control may be the simplest way to avoid the undesirable earth tremors.

In open pit operations seismic activity is related to blasting and slope instability. Even though cases of man-made seismicities are known the hazards are not considered to be extreme (14).

IMPROVEMENT IN MICROSEISMIC MONITORING FOR MINING ACTIVITY

Significant microseismic and seismic activity is known to take place in hard rock mines in Ontario. The most significant mode of improving use of

the monitoring technology is the early warning through the detection of signals, their frequency and location of the source.

The earth is an almost permanent source of microseismic activity. Sources may be related to industrial activities of all kind. Microseismic monitoring of large dams forms the basis of most microseismicity studies required to identify the supplementary induced activity in an industrial undertaking.

In analyzing the variation of emissions with time, it is assumed that there is increased microseismicity with increasing energy release. This concept is not new and research for the prediction of larger seismic activities, such as earthquakes, is in progress. Investigation of Reservoir Induced Seismicity (RIS) is a well established field.

Historically, impoundment of large reservoirs of hydro power plants represents the first type of engineering activity which significantly altered the local state of stress. The stress change in such reservoirs sometimes is related to RIS at about sixty water storages facilities. The highest magnitude of any man-made activity recorded on the Richter Scale was 6.5 at the Koyna dam in India. From an analysis of stress development in any specific site, it is possible to identify the factors leading to such triggering. It is possible to predict potential seismic events at reservoirs (15).

A review of experience in other engineering fields will be useful in framing safety measures to control seismic activity in mining. Evaluation of the triggering mechanisms in mining could be rendered more precise through the identification of stress conditions in mines having similar rock burst problems. Other man-made seismic activity may be reviewed for the purpose of evaluating the critical threshold conditions.

Audible warnings of five to ten seconds prior to failure have been reported in the vicinity of a mine outburst. The typical time lag of audible warning is insufficient for any effective safety measures. Detection of higher frequency noises from development of small cracks in the failure process was suggested as an alternative to extend the warning time (Fig. 5) (16). Field observations suggest that the warning time might be increased to at least fifteen seconds prior to failure.

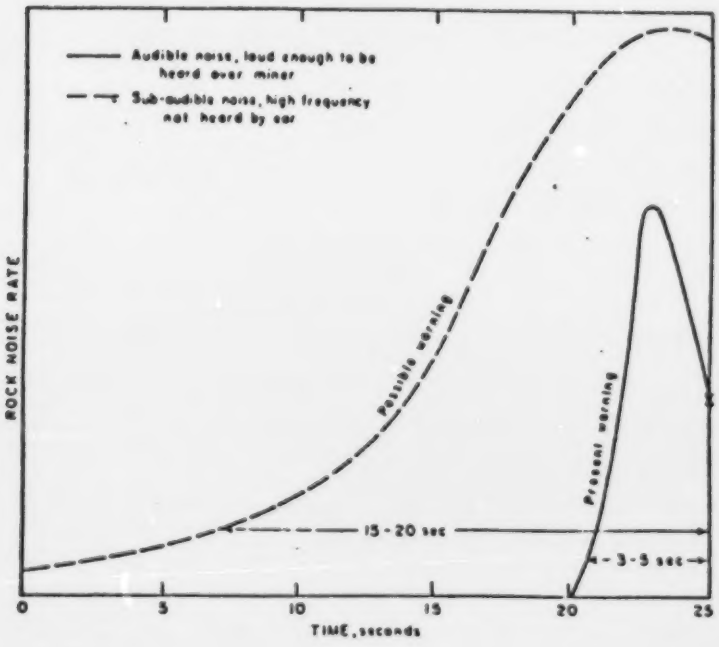

Fig. 5 - Utilization of microseismic emissions for early warning procedures (16)

OTHER EARLY WARNING MONITORING METHODS

Continuous microseismic monitoring has emerged as a practical approach for assessing structural safety of miners. The monitoring and interpreting techniques have been improved and developed for specific sites in different mining operations. Microseismic monitoring is generally considered to be an independent method of detecting high-stress, failure prone zones; and does not require a knowledge of rock properties. This bodes well for its application in mining but the success of current applications is not yet satisfactory for the high level of safety required in mining. Difficulties arise due to the complex mechanism of failure of the geological discontinuities. The mechanism is complex where movement/slippage takes place along discontinuities this response must be addressed for a proper understanding of the behaviour of the mining deposit. This should be studied with respect to other possible mechanisms e.g. change in potential strain energy.

It is important that microseismic monitoring be controlled by a team with a good knowledge of the local mining and geological conditions. Experience confirms that microseismic monitoring is a mature means of monitoring; its degree of sophistication compared to other standard methods appears to be much more advanced and results in complex instrumentation. The dynamic nature of acoustic emissions requires continuous monitoring and requires observations from at least five different locations. Increases in the size of the monitored area requires a significant increase in the points of observation. Systems with up to 64 monitor channels are necessary when several signals must be analyzed rapidly for effective early warning (Fig. 6)(17).

A measure of successful monitoring in ground control is the ability to relate physical behaviour to microseismic emissions. For example, in ground control deformations or support load can be assessed using a model of the field situation for a mining pattern. Such approaches - whether analytical or satistical method, would indicate a range of acceptable deformation or of a certain safety factor. Engineering experience allows the use of such elements in verifying the reliability of thresholds.

Such procedures known as "observational methods" are used in most ground control monitoring (Fig. 7). The observational method uses engineering experience to foresee the future ground response to a particular

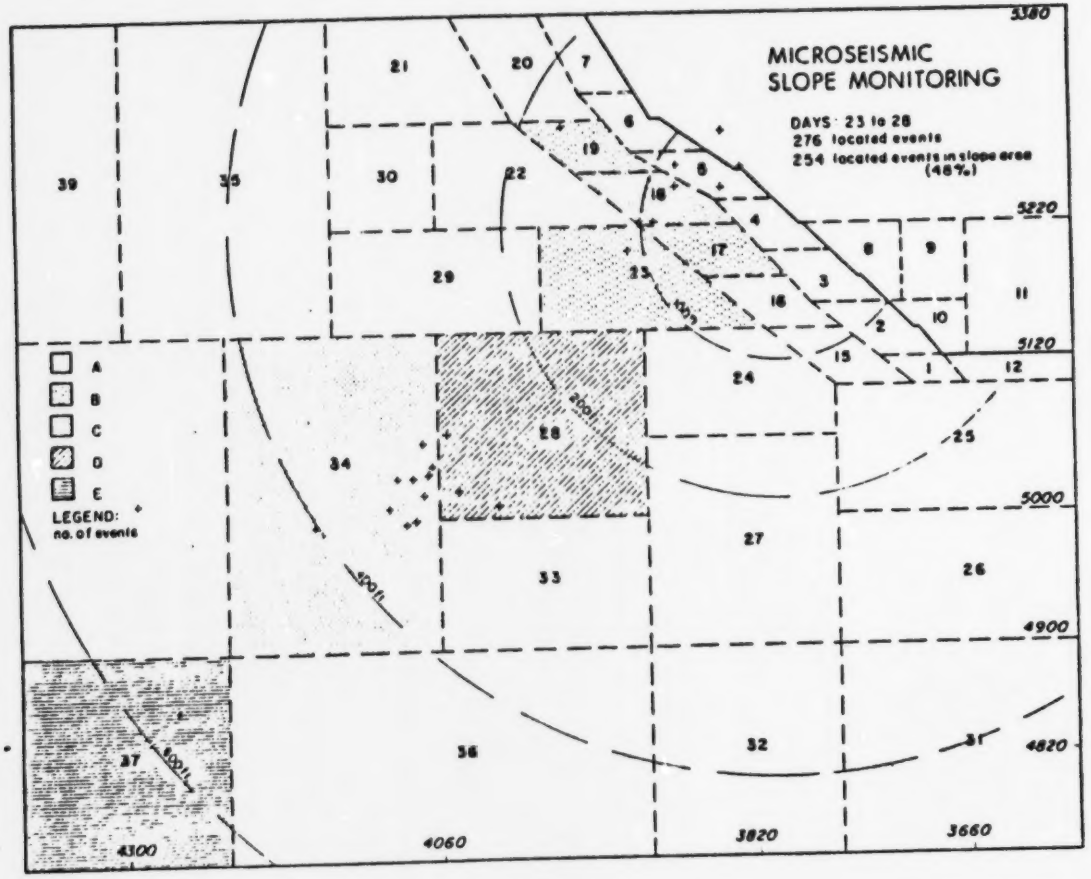

Fig. 6 - Distribution of microseismic events on a cross-section of the slope. CANMET-USBM joint monitoring of pit slope at the Cardinal River Coal Mine, Alberta (17).

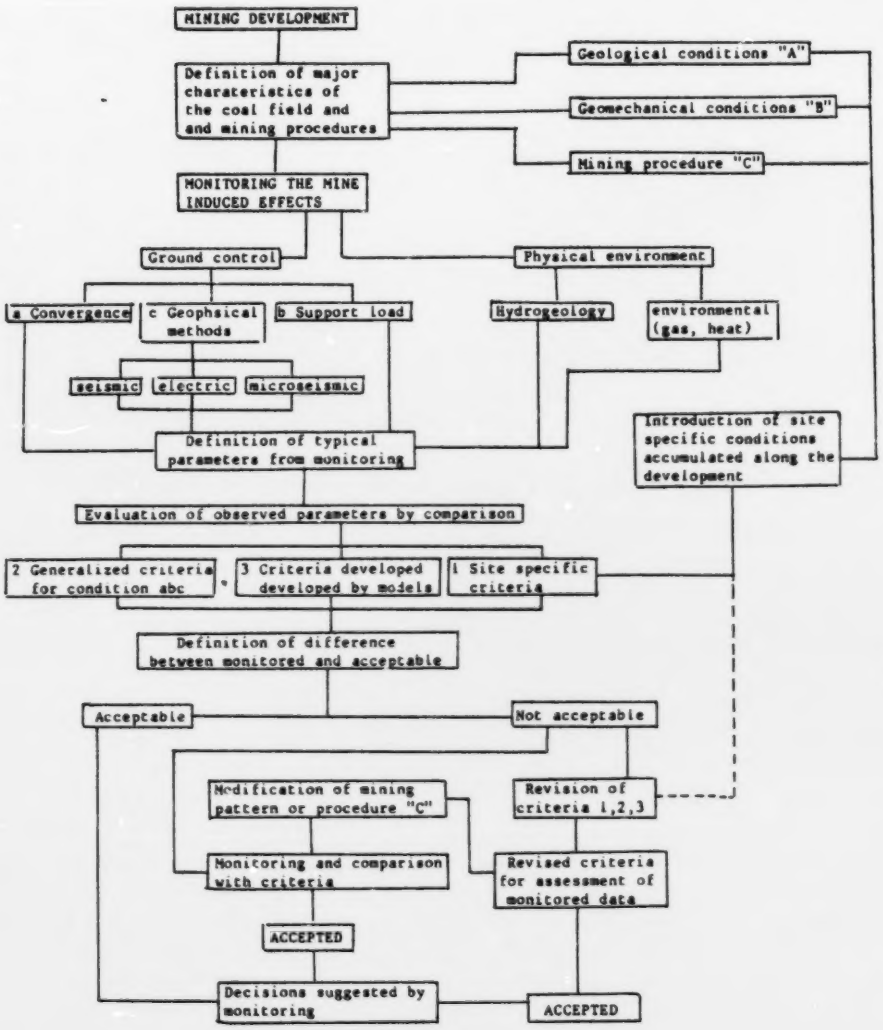
Scope: Development of ground control methods to maximize the mining extraction and reduce the hazard in underground coal fields
MINING DEVELOPMENT
Definition of major charateristics of the coal field and and mining procedures
Geological conditions "A"
Geomechanical conditions "B"
Mining procedure "C"
MONITORING THE MINE INDUCED EFFECTS
Ground control
Physical environment
a Convergence
c Geophsical methods
b Support load
Hydrogeology
environmental (gas, heat)
seismic
electric
microseismic
Definition of typical parameters from monitoring
Introduction of site specific conditions accumulated along the development
Evaluation of observed parameters by comparison
2 Generalized criteria for condition abc
3 Criteria developed developed by models
1 Site specific criteria
Definition of difference between monitored and acceptable
Acceptable
Not acceptable
Modification of mining pattern or procedure "C"
Revision of criteria 1,2,3
Monitoring and comparison with criteria
Revised criteria for assessment of monitored data
ACCEPTED
Decisions suggested by monitoring
ACCEPTED

Fig. 7 - Prediction and control for underground mining (3)

mining development. This includes an evaluation of the conditions most likely to control ground response using one or several most probable response mechanisms. The primary role of the collected data is to confirm the most likely mechanism of ground response. This identification would be used to predict future behaviour during the mining process. Distinct type of data, collected by different monitoring procedures, all contribute to deciding future measures if high hazards are involved.

In using microseismic emissions in ground control problems one must note that the time lag between the warning and events is either not fully known or is relatively short. It is also clear that microseismic monitoring does not currently have available criteria to evaluate the emission in relation to a critical threshold. In practice, the lack of a predetermined threshold limit is often substituted by an arbitrary site specific criterion.

A site specific criterion can be developed through site specific correlations which would define, for example, number of events (rate or accumulated), amplitude of events or microseismic energy. The warning procedure would use some of these correlations that may be available for the monitored area, to draw conclusions by evaluating hazards.

In actual cases the utilization of event monitoring has twin tasks: (a) evaluation of the new observations for their relevance to the existing correlations, (b) improvement of the correlation for use as a warning signal. The tasks call for a significant amount of data processing which should be carried out in conjunction with the evaluation of warning. In current practice the early warning procedure is still hindered by the uncertainty of the time lag between a percursory event and failure development. The necessity for fast assessment of the revelance of site specific criteria is another difficulty.

The site specific conditions are characterized by three elements: geological conditions, geomechanical conditions, and mining sequences. When comparing site specific criteria for microseismic monitoring developed at different mines with that used in relation to other ground control monitoring systems one could arrive at some distinct prediction methods in light of the control flow chart for underground development (Fig. 8). At this stage, microseismic results are essentially site-specific and the ability to frame more generalized transferrable empirical criteria transferable has not been reached. Under simple geological conditions some results expressed in terms

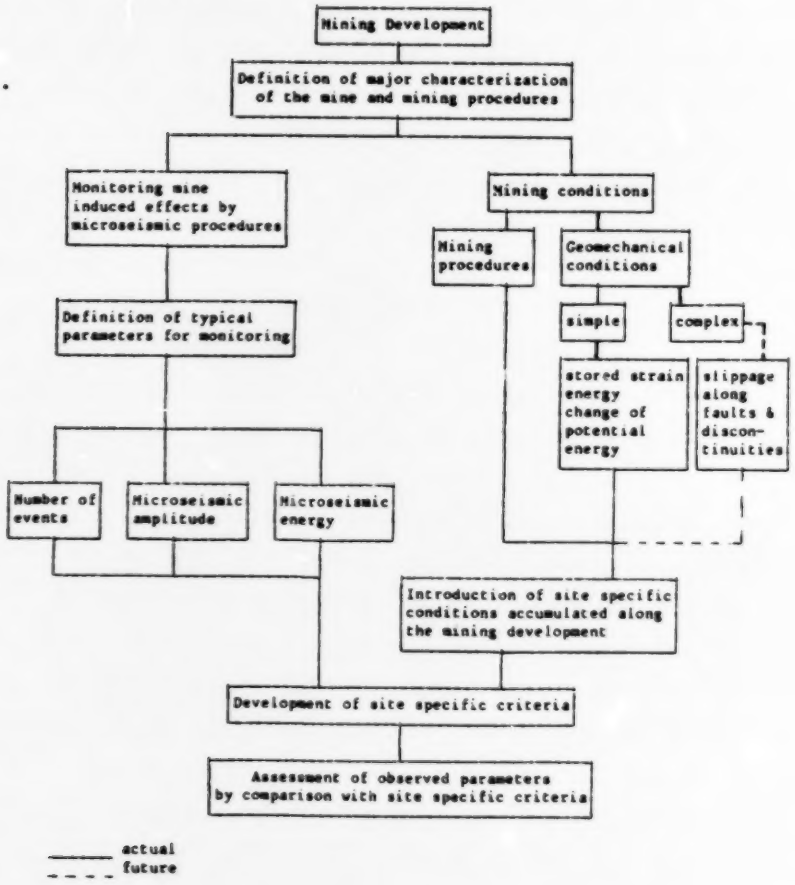
Mining Development
Definition of major characterization of the mine and mining procedures
Monitoring mine induced effects by microseismic procedures
Mining conditions
Mining procedures
Geomechanical conditions
Definition of typical parameters for monitoring
simple
complex
stored strain energy change of potential energy
slippage along faults & discontinuities
Number of events
Microseismic amplitude
Microseismic energy
Introduction of site specific conditions accumulated along the mining development
Development of site specific criteria
Assessment of observed parameters by comparison with site specific criteria
actual
future

Fig. 8 - Microseismic monitoring practice

of stored strain energy or change in the potential energy of the structure studied at one site may be applicable to other equally simple sites.

Despite this, the results of successful application of microseismic observations related to waste disposal, fluid and gas storage and others should be considered for their applications in mining. Research and development should focus more on methodology than on instrumentation with a view to utilizing microseismic data.

RETROSPECT

Monitoring of microseismic activity or acoustic emissions can be used to improve the safety of mines. The knowledge derived from past research together with the development of highly sophisticated instrumentation may increase applications of microseismic methods in mining specially in complex ground control problems.

In considering any contribution of microseismic measurements to mining the following aspects are important.

1. Successful microseismic monitoring should not be considered as a unique approach for reducing ground control hazards. The best chance of success rests on its application in conjunction with the traditional ground control methods. Successful microseismic monitoring requires a detailed knowledge of the local geological and geomechanical environment.
2. The utilization of microseismic methods requires the support of a team of professionals with technical backgrounds in mining, geology, geophysics and also in technologies related to sophisticated measuring equipment and data processing. Even at this time no short term answers could be expected even with a large-scale project.
3. Application of microseismic technology must be site specific. Decisions for microseismic monitoring can only be made after careful screening of relevant experience, equipment and work organization at a particular site.
4. Significant further research and development would be required before microseismic technology may be considered as a standard method in mining. Significant problems are related to hardware and

software for collecting and processing the collected microseismic data. Contribution are expected also from the study of the induced seismic activity aspects of the phenomena and the use of other early warning procedures.

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